Thesis/
Reports
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UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

January 1973

4300
FS-SO-1602-4.6

ESTABLISHMENT AND FIRST PROGRESS REPORT

EFFECTS OF RESTRICTING LAYERS ON WATER MOVEMENT THROUGH COASTAL PLAIN SEDIMENTS

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U.S. GOVERNMENT PRINTING OFFICE : 1968 O—298-607

4300
FS-SO-1602-4.6

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EFFECTS OF RESTRICTING LAYERS ON WATER MOVEMENT

THROUGH COASTAL PLAIN SEDIMENTS

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INTRODUCTION

Vertical movement of gravitational water is often restricted by impervious strata which cause water to flow laterally through the soil and eventually to be discharged into surface drainages. Impermeable horizons in the profile of many Coastal Plain soils and heavy clay layers in the subprofile may have such an effect on natural recharge of the valuable groundwater reservoirs of this region.

In order to properly assess the influence of forests on groundwater recharge, the nature and extent of subsurface lateral flows should be understood since the two are closely tied together. If more water is made available for groundwater recharge by reducing evapotranspiration only to have this extra water drain off laterally and emerge as streamflow, little has been accomplished toward augmenting groundwater supplies. However, if the process of subsurface flow substantially delays the movement of water into the streams, it may have a stabilizing effect on streamflow by reducing peak-flows and sustaining low-flows. This study was designed and established in order to provide information on the processes involved in the lateral flow phenomenon and its effect on natural groundwater recharge and streamflow.

OBJECTIVES

The overall objective of this study, to investigate the effects of vegetative cover reduction on natural groundwater recharge in hydrologically shallow soils, can be subdivided into four specific objectives:

1. To define the surface and subsurface drainage areas contributing to flow at the point of measurement on each plot.

2. To monitor from areas of known size the quantity of surface and subsurface flows above both the B-horizon[1/] and a deep, subprofile clay layer.

3. To estimate the quantity of water seeping through the heavy clay layer.

4. To assess the effects of vegetative cover reduction on surface and subsurface flows and deep seepage through the restricting layer. Objectives 1 and 3 have been achieved and good progress on objective 2 should soon provide the necessary data to begin on objective 4.

INSTALLATION DETAILS

Study Area

An experimental plot was established on each of two contiguous pine-hardwood-covered watersheds (described in detail in Study 1602-5.4). The two watersheds are similar with respect to slope, aspect, vegetative cover and composition, soil type, area, runoff, and depth to restricting layer (comprised chiefly of kaolinite, a non-expanding clay). A map of the two plots including surface and subsurface contours and corresponding drainage areas is shown in Figure 1. The drainage boundary for the B-horizon is assumed to coincide with the surface drainage boundary.

1/ Installations for monitoring water movement above the B-horizon are described in 1602-4.6 Study Plan Addendum dated 2/29/72. Measurements began on November 1, 1971.

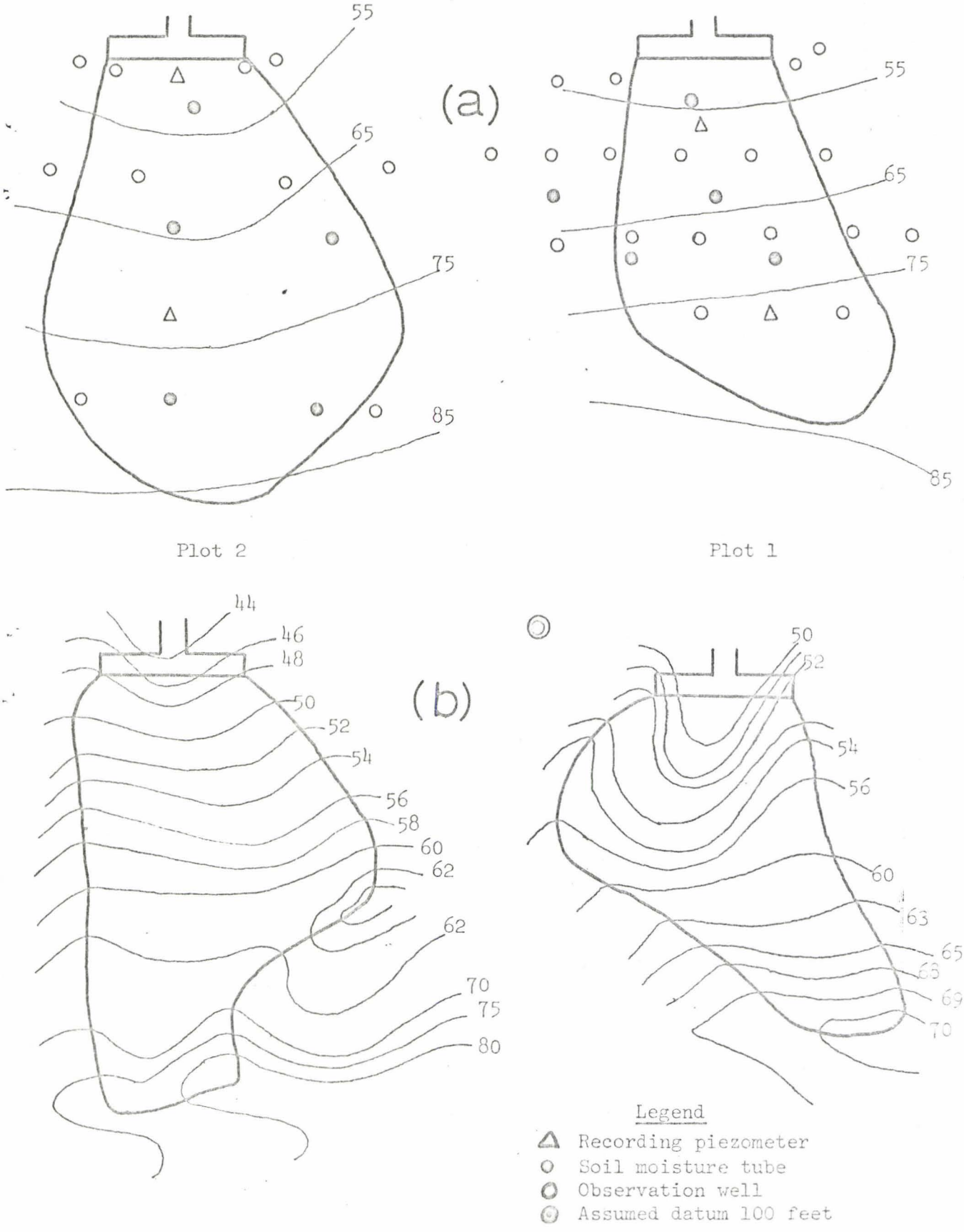

Figure 1.--Experimental plots showing surface (a) and subsurface (b) contours and drainage areas. (Scale: 1" = 40')

The surface drainage areas for Plots 1 and 2 are 5,804 and 9,616 square feet, and their subsurface drainage areas are 4,887 and 7,315 square feet, respectively. The procedures followed in deriving the drainage areas are described in Appendix A.

Soils in the study area were examined and described by A. H. Wynn of the Soil Conservation Service (Appendix B). The upper portion of the watersheds were designated as Lucy loamy sand. Soils on a sideslope near the south boundary of Plot 1 were classed as an unnamed series in the fine-silty mixed thermic family of Typic Paleudalfs. Additional augering on the plots proper indicates that the predominant soil has a relatively deep permeable, A-horizon (18 to 26 inches thick), and maximum accumulation of clay in the upper 12 to 24 inches of the B-horizon. The lower B-horizon grades into deep well drained sands which overlie the dense stratum of kaolinitic clay in the subprofile. Bulk density of the clay material averaged 1.75 ± 0.02 gm/cc (Appendix C).

Deviations from Study Plan

The study plan proposed that surface runoff from the plots be diverted into 55-gallon drums in which the water levels would be continuously measured with water-stage recorders. I later decided to measure both surface and subsurface flow using small flumes. One-half-foot H-flumes were installed to measure surface runoff and 1-foot HS-flumes were used to measure subsurface flow from above both the B-horizon and the clay layer.

The study plan also proposed that five neutron probe access tubes on each plot be located at 10-foot contour intervals along a transect extending down the middle of each plot. Instead, the tubes were spaced as evenly as possible throughout the plots so that they would represent approximately equal portions of the plots (tube locations are shown in Figure 1). Soil moisture readings have been taken at approximately 2-week intervals instead of every three weeks as originally proposed.

Two piezometers instead of one on each plot were equipped with electric water-level sensors connected to water-stage recorders to give continuous records of water-level fluctuations (Figure 1). These measurements were judged adequate to provide necessary information on short-term fluctuations in water levels. From time to time, water levels were measured manually in additional observation wells located on and around each plot (Figure 1).

Installation Schedule

Job	Completion Date
Preliminary survey of subsurface drainage areas	June 15, 1970
Submitted study plan	June 19, 1970
Study plan approved	July 17, 1970
Ordered water-level sensors and recorders	July 17, 1970
Ordered instrument shelters	Aug. 10, 1970
Excavated trenches and lysimeter pits	Sept. 4, 1970
Installed zero-tension lysimeters	Sept. 11, 1970
Ordered flumes	Sept. 18, 1970
Installed sheet metal troughs for surface and subsurface runoff	Sept. 25, 1970
Constructed covers for trenches	Oct. 16, 1970
Constructed earthen terraces around each plot for surface drainage	Nov. 13, 1970
Installed flumes	Jan. 8, 1971
Installed water-level recorders on flumes	Jan. 14, 1971
Received and installed instrument shelters	Jan. 14, 1971
Began measurement of surface and subsurface runoff.	Jan. 14, 1971
Constructed piezometer wells	Mar. 5, 1971
Installed water-level sensors and recorders	Mar. 11, 1971
Began operation of recording piezometers	Mar. 11, 1971
Installed neutron probe access wells	Mar. 26, 1971
Began soil moisture measurements	April 2, 1971
Defined subsurface drainage areas	May 31, 1971
Installed troughs and flumes for measuring runoff above B-horizon	Nov. 1, 1971
Prepared addendum to study plan	Feb. 21, 1972
Study plan addendum approved	Feb. 29, 1972

Installations, Measurements, and Records

Subsurface Flow Above Restricting Layer

Since the installations for measuring subsurface flow were completed in January 1971, numerous runoff events have been recorded, with peak flows ranging from trace amounts to more than 0.04 cfs. The greatest quantity of subsurface flow measured thus far resulted from a total of 4.0 inches of rain that fell on February 19 and 21, 1971. Total subsurface flow amounted to 1.6664 area-inches on Plot 1 and 2.2136 area-inches on Plot 2.

Subsurface flow was not always greater on Plot 2 than on Plot 1. In many of the smaller storms the opposite was true. Although Plot 2 was larger in area than Plot 1, its depth of soil above the restricting layer (hence the water storage capacity) was also greater. Once the storage capacity was exceeded, Plot 2 generally drained for a longer period of time and discharged more water, but, for some smaller storms with low antecedent soil moisture, subsurface flow was greater on Plot 1.

A conspicuous feature of most of the subsurface flow hydrographs when compared with the rainfall charts was the quick response of flow to precipitation. In many instances subsurface flow began within 20 minutes after the rain started. Several researchers have observed this phenomenon (1, 4, 6, 7, 9, 10) but the quickest response reported was 90 minutes after rainfall began (8). Aubertin (1), Pierce (6), and Whipkey (9) attributed the quick response of subsurface flow chiefly to saturated

drainage through old root channels and structural cracks open to the atmosphere. Troendle (7) and Zimmermann (10), however, felt that the quick response was a function of water displacement created by the addition of water in excess of the storage capacity of the soil. Hewlett and Hibbert (4) referred to this type of movement as "translatory flow." In effect, soil water downslope near the trench is forced out of the soil simply by water pressure exerted from upslope rather than by actual water movement throughout the entire length of the slope. Horton and Hawkins (5) discovered that displacement occurs even in unsaturated conditions as a result of forces being conveyed through continuous films of water surrounding soil particles. It is likely that in most situations both of these factors--root channel flow and water displacement--hasten the appearance of subsurface flow after a storm begins.

The following calibration regression was computed for the two plots with respect to subsurface flow:

$$\hat{Y} = 0.76925X + 0.01678;\ r^2 = 0.989;\ \bar{X} = 0.1717,\ \bar{Y} = 0.1488$$

where $\hat{Y}$ is expected subsurface flow (area-inches) from Plot 1 and X is observed subsurface flow from Plot 2. The regression (based on data from 24 storms--Figure 2 and Appendix D) is highly significant, indicating that the plots have similar hydrologic responses. The standard error of estimate for the regression is ± 0.0392 area-inch.

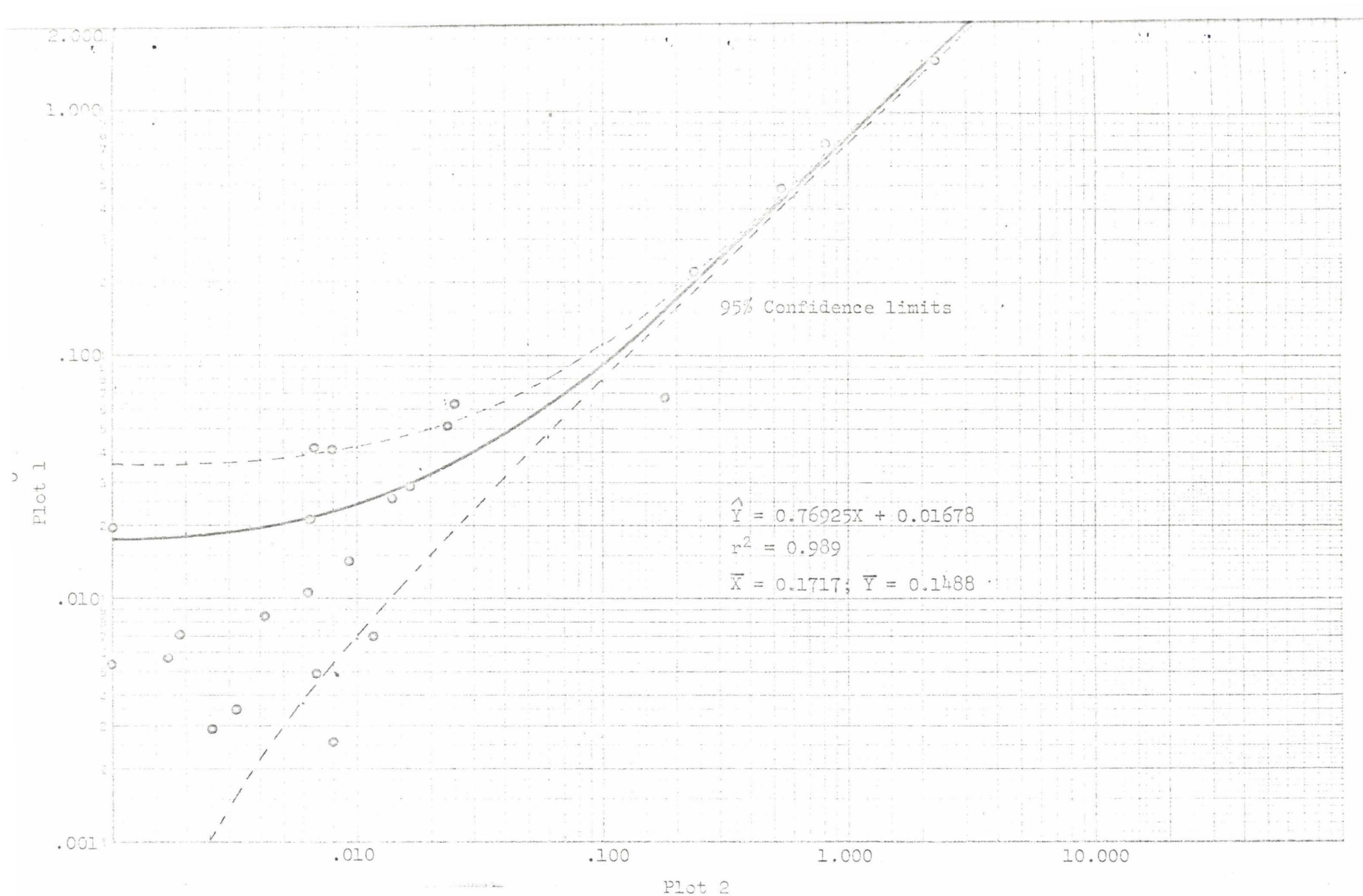

Figure 2.--Calibration curve for subsurface flow (area-inches) from the study plots based on data from 24 storms.

Surface Runoff

Surface runoff is not a common occurrence on the study plots. In fact, there have been only four storms that produced surface runoff on both plots since the study began. The largest quantity of surface runoff from these storms was 0.022 area-inch. For each of the four storms, maximum rainfall intensity (10-minute interval) during the period of surface runoff was computed. The lowest maximum intensity observed for the runoff-producing storms was 2.3 inches per hour. This storm, which occurred March 6, 1971, dropped 0.4 inch of rain during a 10-minute period.

It is apparent that surface runoff on the study plots is not solely a function of rainfall amount and intensity. There were several storms having intensities and quantities of precipitation equal to the four storms mentioned above, but which did not produce surface runoff. Obviously, antecedent soil moisture status is of paramount importance in determining surface runoff. However, when soil and litter are wet there appears to be a threshold of rainfall intensity below which surface runoff will not occur. The storm that occurred September 26, 1971, would tend to support this viewpoint. On that date, rain fell continuously during a 5-hour period from 1:15 p.m. until 6:15 p.m. During that time, 5.6 inches of rain fell. However, there were only two brief intervals during the storm that produced surface runoff. Maximum rainfall intensity (10-minute interval) during these two periods of surface

runoff was approximately 5.4 inches per hour. Maximum intensity during the non-runoff-producing intervals exceeded 2.0 inches per hour. Measurable quantities of surface runoff were never produced by storms with intensities below 2.30 inches per hour (excluding periods when the soil surface was frozen) even when litter and the upper soil horizon were wet.

High detention storage capacity of the litter and rapid infiltration of water into the light textured A-horizon combine to reduce surface runoff on the upper slopes of the pine-hardwood-covered watersheds. If the pine-hardwood cover is disturbed so that the litter cover is not maintained on the soil there will likely be a significant increase in surface runoff. This hypothesis will be investigated after an adequate calibration of the plots has been achieved. Even with only four runoff-producing storms included in the regression analysis, a close relationship was observed between the quantity of runoff produced on the two plots. A significant coefficient of determination ($r^2 = 0.910$) was obtained for the regression that can be written

$$\hat{Y} = 0.88703X + 0.00022;\ \bar{X} = 0.0090,\ \bar{Y} = 0.0082$$

where $\hat{Y}$ is expected surface runoff (area-inches) on Plot 1, X is measured surface runoff on Plot 2, $\bar{X}$ is mean runoff (area-inches) on Plot 2, and $\bar{Y}$ is mean runoff on Plot 1. The standard error of estimate for the regression is ± 0.003 area-inch.

Lateral Water Movement Above B-Horizon (Interflow)

Since the installations for measuring flow above the B-horizon were completed November 1, 1971, only one storm (July 3, 1972) produced

interflow from this stratum on both plots. The 4.50-inch storm that occurred on July 3 was more intense (high 10-minute intensity of 3.20 inches per hour) than many of the winter storms that failed to produce interflow. Furthermore, by July 3 the soils (including the B-horizon) were well into their summer drying cycle. With less water in the micro- and macropores of the B-horizon there is proportionately more air within these interconnected pores. Consequently, when a soil is dry there is a greater likelihood of temporary entrapment of air bubbles in the pores when a saturated front of water moves downward. If the flow of water through the dense B-horizon is impeded by trapped air bubbles the water would have a tendency to move laterally through the A-horizon which generally has a greater abundance of horizontally trending root channels and also more earthworm activity (1). On the other hand, when soil moisture in the B-horizon is near field capacity there is less likelihood of the vertical passage of water being blocked by trapped air. This may help explain the more common occurrence of interflow during periods when soil moisture is low.

Vertical Water Movement Through Restricting Layer

After the failure of the zero-tension lysimeters to properly measure water movement through the clay, two alternative approaches were tried. Measurements of hydraulic conductivity in undisturbed soil cores (3-inch diameters) were used to estimate the quantity of water transmitted under saturated conditions. However, certain problems encountered in collecting the core samples cast some doubt on the accuracy of results

obtained. Even though the samples were collected at a time when soil moisture was relatively high (there was even a saturated zone above the clay layer) the clay materials several inches below the top of the layer were, in many cases, brittle. As the brass collecting rings were driven into place, cracks were often formed in the samples. These cracks resulted in higher percolation rates during laboratory measurement of hydraulic conductivity. Evidence of disportionate amounts of flow through cracks was observed in many of the samples after water dyed with methylene blue chloride was passed through them. However, it was impossible to tell if the cracks observed were those caused by sampling or were, instead, naturally occurring structural cracks. Average conductivity as measured in the laboratory was 0.0188 ± 0.0037 inch per hour. Obviously, the variability was quite high (coefficient of variation was 106 percent). Of the 29 clay samples analyzed, 12 had conductivity values of 0.002 inch per hour or less. On the other extreme, 9 samples had conductivities in excess of 0.030 inch per hour. These latter samples are suspect. Repeated in situ measurements of saturated conductivity using a modification of the shallow well pump-in method (Appendix E) indicated the saturated conductivity of the dense clay material was 0.00012 ± 0.000008 inch per hour. This strengthens my belief that cracks formed during the core-sampling process were responsible for some of the high laboratory readings.

Continuous measurements of water ponded above the restricting layer in addition to periodic measurements taken in observation wells on each plot provided the data necessary for estimating hydraulic head above the clay layer during each period of saturation. During the period from March 11, 1971, to May 17, 1971, hydraulic head averaged 1.54 feet on Plot 1 and 1.14 feet on Plot 2. Knowing the hydraulic conductivity of the clay material and the mean hydraulic head above the clay, we can compute the amount (area-inches) of water moving through the clay using a modification of Darcy's equation:

$$Q = \frac{12\ K\ t\ \Delta\ H}{L}$$

where Q is area-inches of water transmitted through the clay, K is hydraulic conductivity (feet per hour), H is average hydraulic head (feet), L is the thickness of the clay layer, and t is time in hours.

The following measurements were used to compute the quantity of water (area-inches) transmitted through the clay on the sample plots during a 2-month period in 1971 and a 5-month period in 1972:

Plot No.	Time period	K	t	H	L	Vertical flux thru clay	Precip. during interval
		Ft./hr.	Hours	---Feet---		-----Area inches-----	
1	3/11/71-5/17/71	0.00001	1,488	1.54	10	0.21	9.59
	12/27/71-6/5/72	.00001	3,816	.93	10	.50	19.28
2	3/11/71-5/17/71	.00001	1,488	1.14	10	.20	9.59
	12/27/71-6/5/72	.00001	3,816	.58	10	.48	19.28

It is apparent that the quantity of water seeping through the dense clay layer is small in comparison to the amount of precipitation occurring during these intervals.

Soil Moisture

Soil moisture measurements have been taken with a neutron probe at approximately 2-week intervals since April 2, 1971. The soil moisture data will be analyzed as soon as the Nuclear-Chicago probe has been properly calibrated. The measurements have been taken to depths of 3 to 5 feet into the clay material.

Analysis of Representative Storms

An analysis of several storms was made with respect to subsurface flow, surface runoff, and ponding of water above the heavy clay layer, in an attempt to gain some insight into the hydrologic processes governing these responses.

Storm of June 27, 1971.--A 1.12-inch rain, of which 0.90 inch fell within a 20-minute period, produced both surface and subsurface runoff on the two plots (Figure 3). Subsurface flow began to drain through the flumes on each plot approximately 15 minutes after the storm began. The piezometers showed no ponded water above the clay layer at the time of the storm. Neither was there a subsequent ponding of water after the rain stopped. This indicates that subsurface flow occurs even in the absence of ponded water above the restricting layer and supports the theory that much of the flow takes place through root channels and cracks. A second period of rainfall starting about 4 hours after the first and amounting to 0.22 inch resulted in another rise in the subsurface hydrograph on Plot 2 only. The second rise was gradual rather than steep

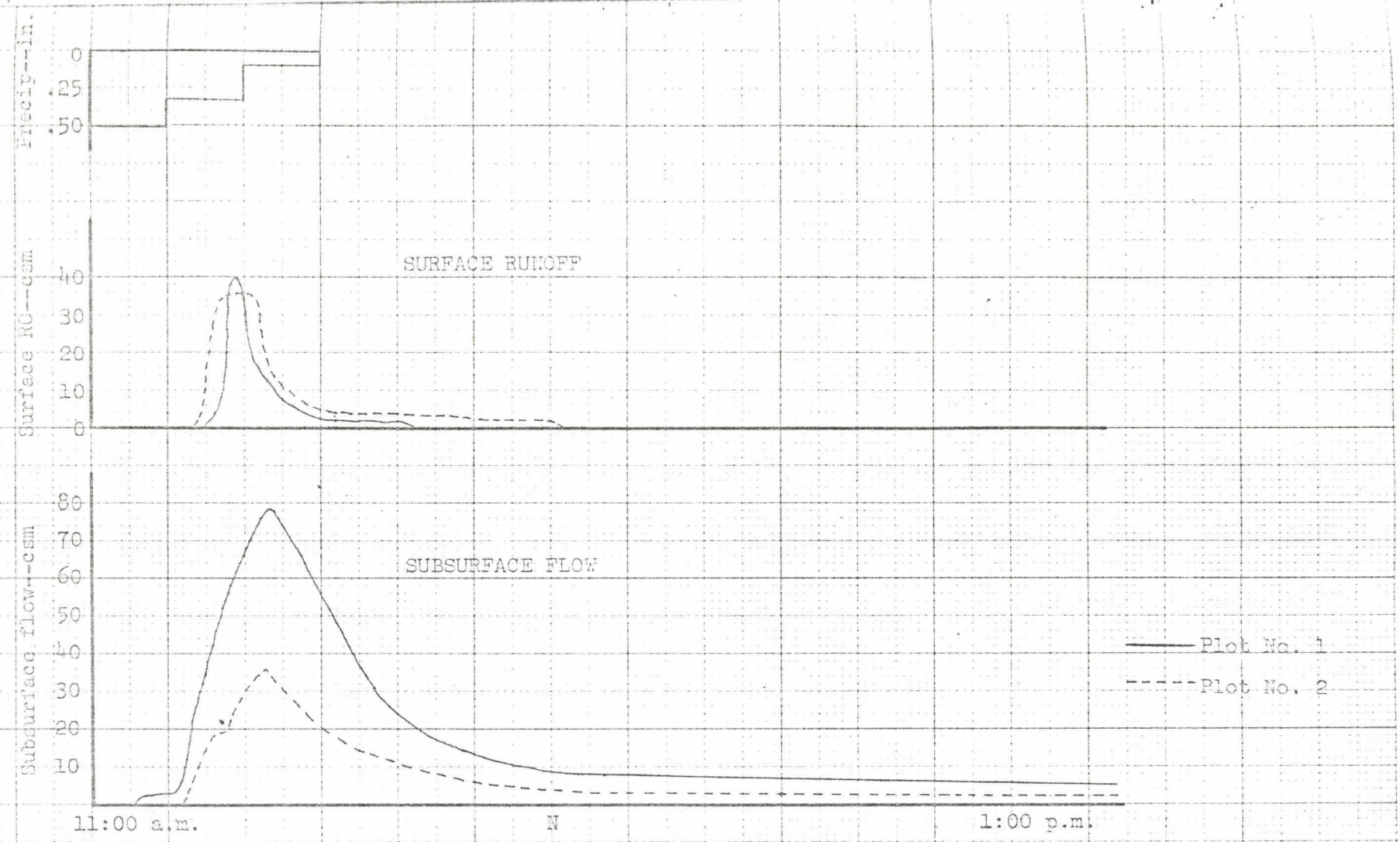

Figure 3.--Comparison of surface and subsurface flow hydrographs between plots for the storm of June 27, 1971.

like the first. Subsurface flow amounted to 0.0503 area-inch from Plot 1 and 0.0236 area-inch from Plot 2. Installations for separating outflow above the B-horizon were not completed until November 1971; consequently, subsurface flows measured prior to that time may have also contained water contributed from interflow.

The storm of June 27, 1971, produced very little surface runoff on the two plots. Runoff was 0.0034 area-inch on Plot 1 and 0.0073 area-inch on Plot 2. The surface runoff hydrographs (Figure 3) for both plots had steep rise and recession traces indicating no appreciable residual runoff. The runoff was likely caused by the "shingle-effect" of a moderate cover of undecomposed hardwood litter, and probably originated from a relatively small area above the flumes.

Storms of July 23 and 24, 1971.--These two storms are discussed together because they occurred within a 24-hour period. On July 23, 1.35 inches of rain fell attaining a maximum intensity of 4.50 inches per hour. On July 24 another 0.65 inch fell at a maximum intensity of 2.40 inches per hour. Both events produced subsurface flow (Figure 4), but only the first storm produced surface runoff. Subsurface flow from the second smaller storm was influenced by the previous storm. Many times there were rains in excess of 0.65 inch which produced no subsurface flow. This suggests that antecedent soil moisture is an important factor affecting subsurface flow.

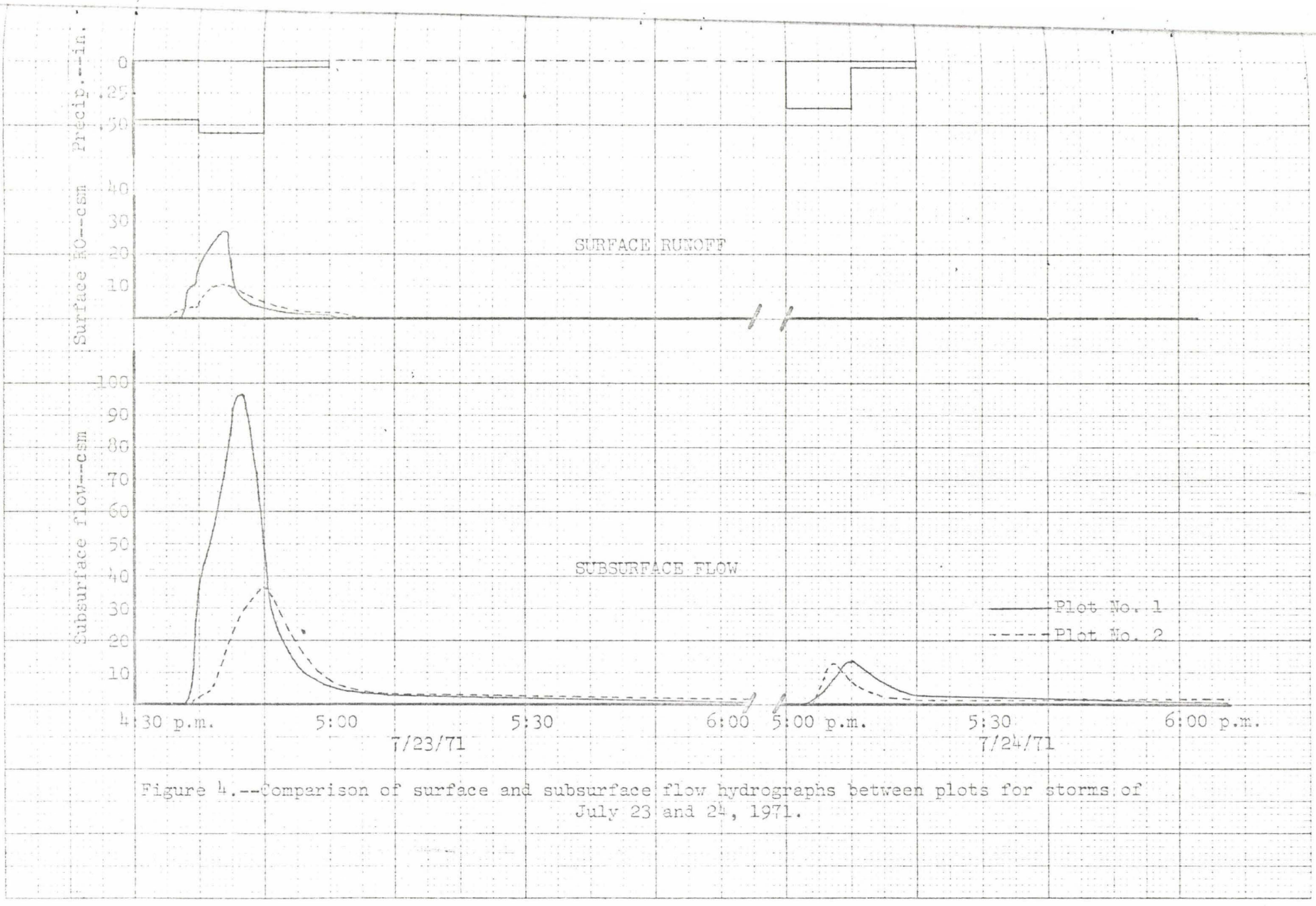

Figure 4.--Comparison of surface and subsurface flow hydrographs between plots for storms of July 23 and 24, 1971.

Subsurface flow was greater on Plot 1 during the first storm (0.0264 area-inch as compared with 0.0138 area-inch on Plot 2), but nearly the same for both plots (0.0035 area-inch on Plot 1 versus 0.0034 area-inch on Plot 2) during the second storm after soil moisture had been partially recharged.

No ponding of water above the restricting layer was detected by the piezometers after either of these two storms.

Storm of September 26, 1971.--On this date 5.60 inches of precipitation fell within a period of 5 hours. There were three separate intervals during the course of the storm in which rainfall intensity was great enough to cause distinct peaks on the subsurface runoff hydrographs. Only two peaks were shown on the two surface flow hydrographs (Figure 5).

Peak subsurface flows (all three peaks) were greater for Plot 1 than for Plot 2. Total subsurface flow was also slightly greater on Plot 1 (0.2396 area-inch) than on Plot 2 (0.2236 area-inch). The recession curve for Plot 2 was more drawn out than for Plot 1. This was probably due to the deeper soils on Plot 2 which took longer to drain.

Surface runoff amounted to 0.0205 area-inch on Plot 1 and 0.0219 area-inch on Plot 2.

Unfortunately, the piezometers were malfunctioning at the time of the September 26 storm. As a result, it was not possible to assess the effects of this large storm on the ponding of water above the clay layer.

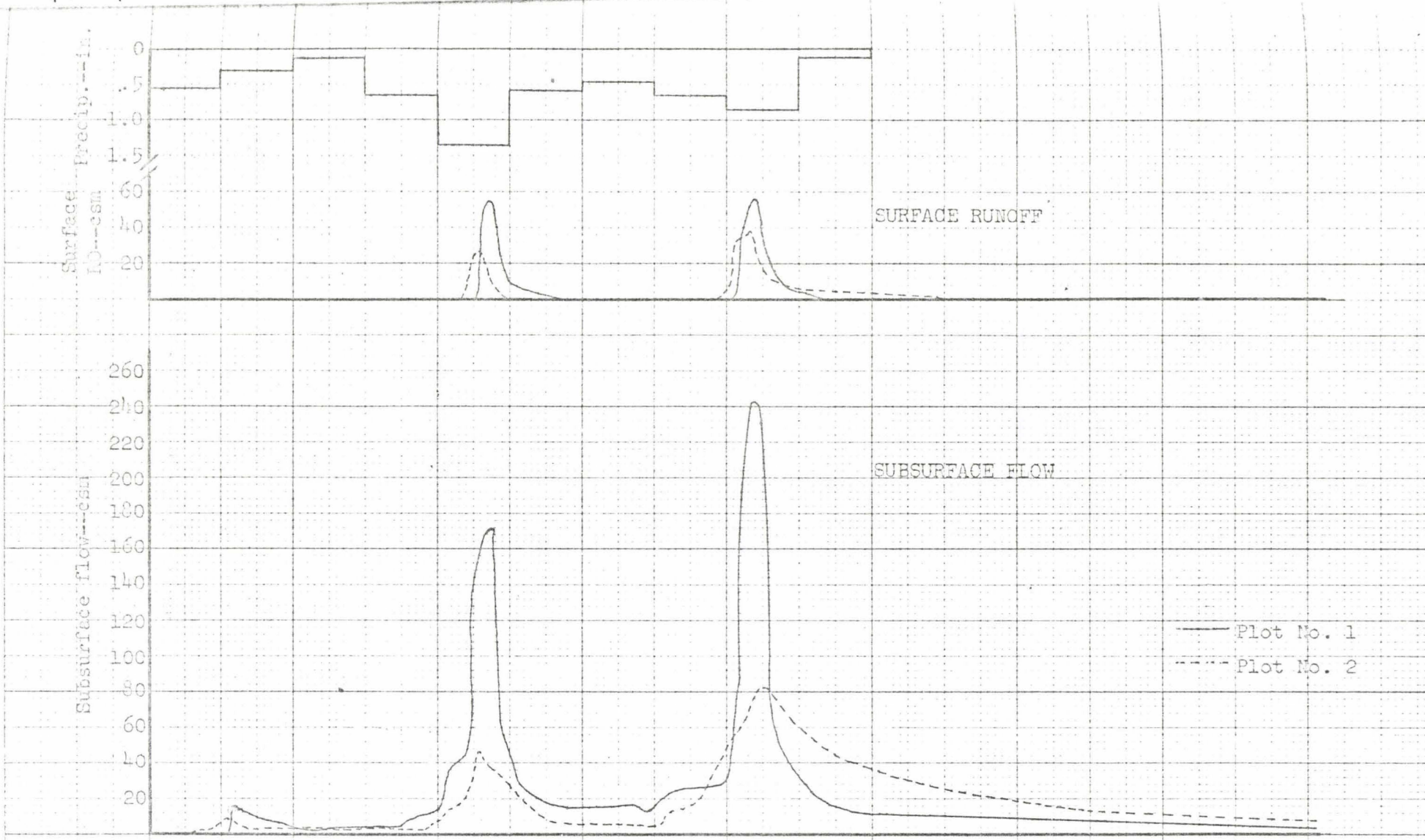

Figure 5.--Comparison of surface and subsurface flow hydrographs between plots for storm of September 26, 1971.

Storm of May 7-8, 1972.--This storm, which began on May 7 and continued into the next day, delivered 3.05 inches of rain to the study area. During the first period of rainfall 0.75 inch fell gently within a period of 6 hours. The second segment of the storm several hours later was more intense with 2.30 inches falling in approximately the same length of time. Although a small amount of subsurface flow was recorded on Plot 1 after the first segment of the storm, no flow occurred on Plot 2. Furthermore, during the second part of the storm subsurface flow on Plot 1 began 3-1/2 hours sooner than on Plot 2 (Figure 6). However, once subsurface flow began on Plot 2, it continued longer than on Plot 1 and amounted to 0.118 area-inch more total runoff. The difference in response to precipitation between the two plots was a function of water storage capacity which was greater on Plot 2.

There was no measurable surface runoff or flow above the B-horizon on either plot during or after this storm. There was, however, a pronounced rise in the water levels above the clay layer. Before the storm the water level near the lower edge of Plot 1 was 1.85 feet above the clay and 0.50 foot on the lower part of Plot 2. The response on Plot 2 occurred within an hour after the rain; however, there was a lag of 24 hours on Plot 1. A peak level of 5.32 feet was reached 84 hours after the storm on Plot 1, and a peak of 3.30 feet was reached 42 hours after the storm on Plot 2 (Figure 7). No definite explanation can be offered for the 24-hour lag in the water level rise on Plot 1 in light of the quick response on Plot 2. The water level in the upper well on Plot 1 also began rising very quickly (3 hours) after the storm.

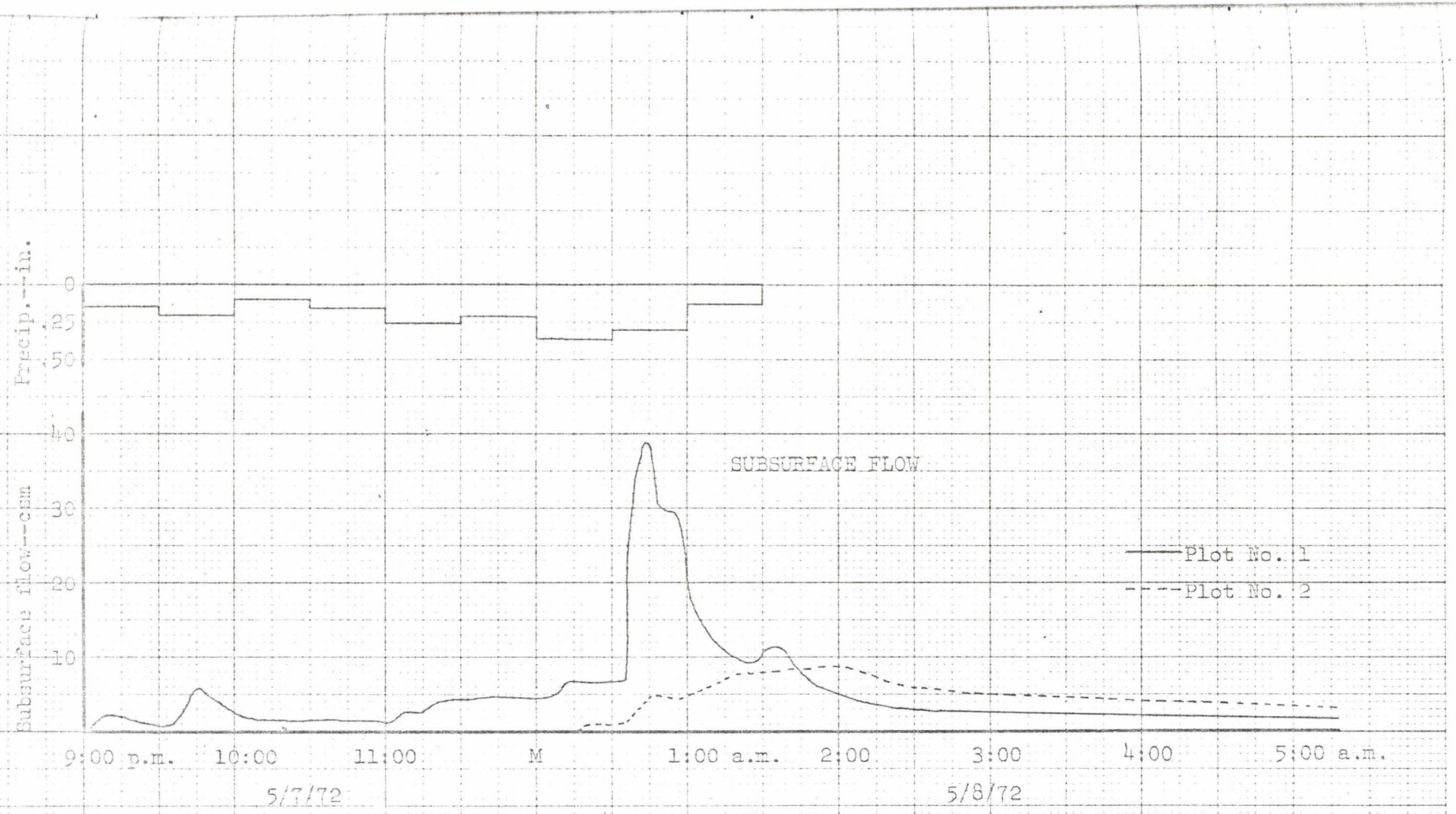

Figure 6.--Comparison of subsurface flow hydrographs between plots for storm of May 7-8, 1972.

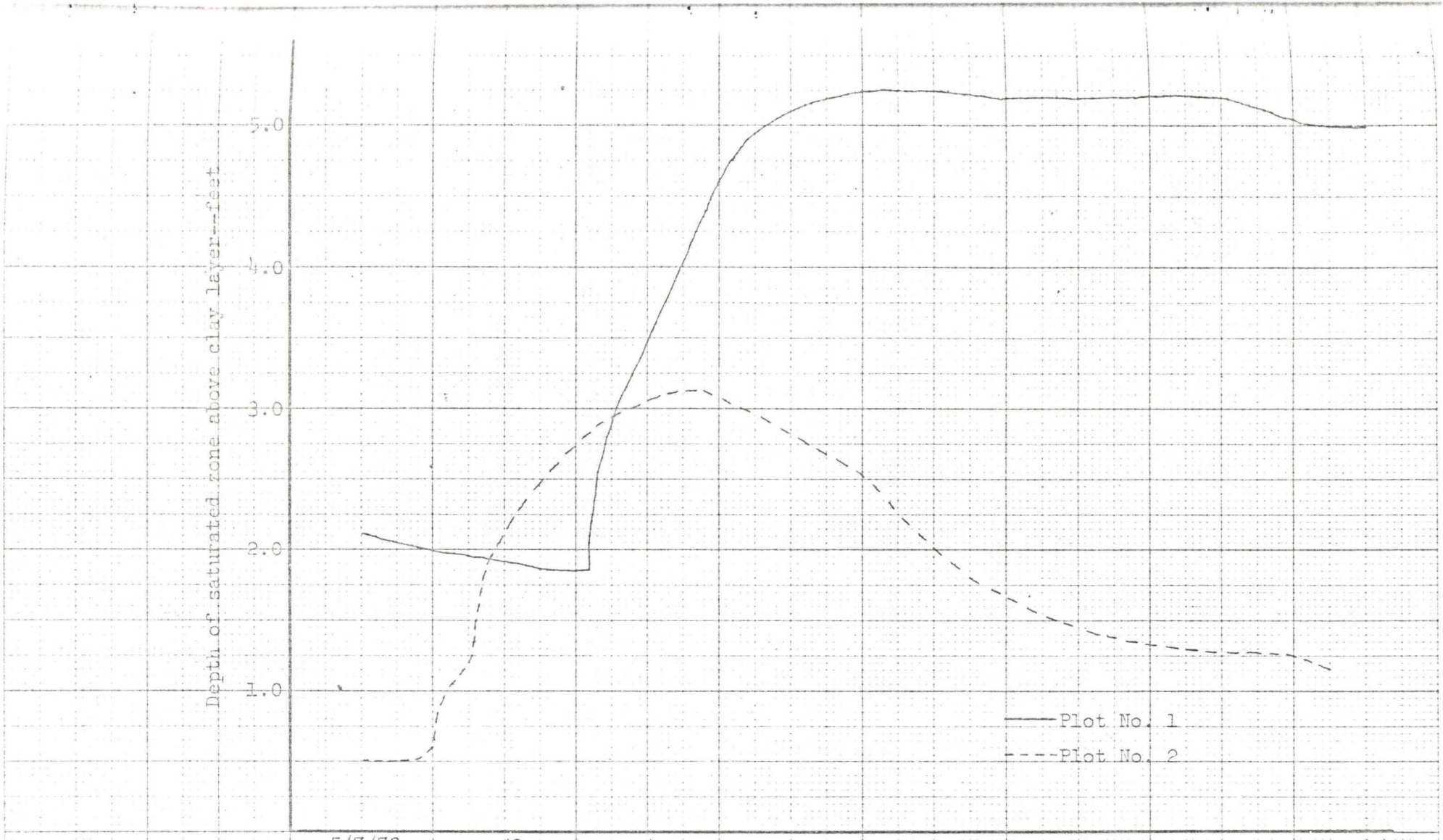

Figure 7.--Response of perched water table (above deep clay layer) to storm of May 7-8, 1972, measured near outflow trenches of Plots 1 and 2.

DISCUSSION

This study is concerned principally with three hydrologic parameters: inflow, outflow, and storage.

Assuming the surface and subsurface drainage areas for each plot have been adequately defined and that upward movement of soil water is negligible, inflow is easily measured by a network of raingages. However, the assumptions, especially the latter, may not hold under all circumstances. It is well known that during dry periods upward gradients of soil moisture potential can develop in the profile, resulting in unsaturated movement of water toward the soil surface. Although appreciable upward flux could conceivably occur during prolonged drought, it is generally considered to be negligible. Defining the areas contributing to subsurface drainage on the unbounded plots is also subject to some degree of error. There is a practical limit to the number of holes that can be augered to the clay layer for the purpose of plotting the subsurface contours. There may be undetected ridges or rills in the clay layer that would tend to influence the quantity of water flowing into or out of the plots. Additional holes will be augered around the periphery of each plot in order to refine the boundaries if "leaks" are suspected after water balance equations have been computed.

Outflow from the plots can occur as evapotranspiration, surface runoff, interflow above the B-horizon, subsurface flow above the clay layer, or percolation through the clay. Evapotranspiration is not measured. It is determined indirectly only after inflow, storage and the other forms of outflow have been determined. Measurement of surface

runoff, interflow, and subsurface flow has presented few problems thus far, with the exception of occasional mechanical problems with the water level recorders. In considering the amount of water percolating through the clay layer, several points are apparent. Although it would have been preferable to have a direct measurement of the actual quantity of water seeping through the clay layer, the indirect approach used in this study provides evidence that this outflow component is relatively minor. The extreme difference in hydraulic conductivity between the clay (0.00012 inches per hour) and that of the overlying loamy sand, and the downslope hydraulic gradient above the clay layer dictate a lateral movement above the clay layer (following the path of least resistance) rather than a vertical movement through the clay. This, of course, has important implications from the standpoint of groundwater recharge. Areas underlain by dense clay layers offer little prospect for increasing natural groundwater recharge by manipulating forest cover.

Storage, the third parameter considered in this study, includes water held in soil pores against the pull of gravity as well as free water ponded above the restricting layer. Although rapid movement of water through the soil was indicated by the quick response in subsurface flow at the flumes, there were also indications of delayed flow. Many times the flumes continued to drip for several days at an unmeasurable rate. This delayed flow represents water that is slowly being released from storage. It further complicates the process of attempting to account for the disposition of precipitation from each individual storm. The soil moisture data when analyzed will probably shed some light on this aspect of the study.

Preliminary results of this study suggest that overland flow plays only a minor role in the hydrology of small watersheds with ample vegetative cover. However, it is also apparent that subsurface flow behaves much like overland flow in its effect on streamflow. The flashy nature of subsurface flows especially during intense storms greatly reduces their effectiveness in minimizing streamflow peaks or in sustaining low flows during dry periods.

Although sheet erosion is less likely to occur if subsurface flow is the primary outflow mechanism for a watershed, there are indications that channel erosion does occur where subsurface flows discharge into ephemeral channels. In some cases subsurface flows discharge into the channels with considerable velocity from tunnel openings several inches in diameter.

FOLLOW-UP INSTRUCTIONS

The calibration period should be extended long enough to assure reliable calibration of the two plots at least with respect to subsurface flow above the deep clay layer. It may not be practical or even needful to calibrate the plots for surface runoff and lateral flow above the B-horizon. It is likely that substantial increases in either surface runoff or lateral flow above the B-horizon induced by stand reduction could be recognized by subjective comparison of pre-treatment and post-treatment responses. These components of the hydrologic cycle appear to be relatively minor in comparison to the subsurface flow.

In light of the revision of the RWUD for 1602, dual objectives could be considered in continuing this study. Not only could the original objectives be pursued, but additional objectives compatible with the revised RWUD (and Study 1602-5.4) could easily be integrated into the study.

The low permeability of the restricting layers underlying the study plots affords an opportunity to study the disposition of rainfall without some of the usual problems that arise from a water budget approach. Deep percolation which complicates most water budget studies appears to be minor in this situation. In light of this it should be possible to compute evapotranspiration with relatively good accuracy once the soil moisture data has been analyzed.

Surface runoff from the two contiguous watersheds on which the study plots are located has been continuously measured since 1959. Comparing the flow characteristics of the watersheds with those of the plots may afford a better understanding of the processes that influence runoff from small watersheds.

RECOMMENDATIONS

Prepare a manuscript based on results of this study for publication as a Southern Station Research Paper.

LITERATURE CITED

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APPENDIX

(Appendixes A, B, C, D, E)

APPENDIX A

Procedures for Determining Contributing Areas For Surface and Subsurface Flows

Preliminary augering defined the general configuration of the kaolinite layer in the study area. On the basis of these initial measurements, a grid pattern (40-foot spacing) was established on each of two areas (located on contiguous watersheds) thought to be suitable for study plots. The sample points on the grid (laid out with a staff compass and engineers tape) were permanently marked with wooden stakes treated with a preservative. Surface elevation at each stake (in reference to an assumed datum of 100 feet---Figure 1) was accurately obtained with a Dumpy level. A hole was augered to the clay layer at each stake and the exact depth to the clay was recorded. The elevation of the clay at each point on the grid was determined by subtracting depth to clay from the surface elevation. For each plot a separate contour map (drawn to scale) was constructed for surface and subsurface elevations. These maps were used to determine the best possible locations for the interceptor trenches. After the trench locations were chosen the subsurface contour maps were refined by augering additional holes at 20-foot spacings and the surface and subsurface drainage boundaries were outlined on the maps and planimetered to determine areas.

APPENDIX B

PINE-HARDWOODS WS 2 SOIL DESCRIPTION 1602-4.6 U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

Soil name ? UNNAMED SERIES IN Fine-Silty mixed thermic Family of Typic Paleudalfs File No.

Profile CR. WSFS Hydr lab Date 6-1-72 Stop No.

Area Rt 1

Mixed Pine - Hardwood Climate Humid

Middle S.B. long steep side slope

steeply sloping	Drainage		Salt or alkali
	Gr. water		Stoniness
	Moisture		
	Root distrib.		

light

Moderate to slow above 35 inches, slow below 35 inches

Notes: Colluvial

Appears as probably a material from upslope on

slope.

Color of this material hard to tell as appears like

on the lower slopes and crops out in

Hori-zon	Depth	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Reaction	Boundary		
A		Partially decayed		Organic								
-2		10YR 8/2		SL	Mas-		Vfr		CS			
-10		10YR 5/3		SL	Mas		VFr		CS			
-36		7.5YR 5/4	C1-2 7.5YR 7/8 7.5YR 5/6	SiCl	2m sbk		s f	w sp	SS		Few coats	Few fine
-52		7.5YR 4/8	C1-2 10YR 6/3	SiCl	2m sbk			w sp			Few thin coats	Com fine
-72		Mottled 10YR 5/8 & 7.5YR 6/6	C1-2 reduc & yellowish brown	SiC to SiCl	2m			w ps			Black stains	Few

32

SOILS-232G 4-70 CODE SOILS-11

PINE HARDWOOD WS 2 — APPENDIX B — SOIL DESCRIPTION — 1602-4.6

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

type Lucy loamy sand — File No.

Lafayette Co. — USFS Hydr. Lab — Date 6-1-72 — Stop No.

sification Loamy, siliceous thermic family of Arenic Paleudults

ition Pine-hardwood watershed 2, 18 ± ab

g. (or crop) Mixed pine hardwood — Climate

ent material Coastal Plain material

iography Edge of ridge top

ef Gently sloping — Drainage Well drained — Salt or alkali

ation — Gr. water — Stoniness

e 3 %+ — Moisture Moist throughout

ect — Root distrib.

sion Slight

meability Rapid in A horizon, moderate in B horizon

ditional notes

Pine pines on this site.

This soil is slightly outside the Series' range

Depth	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Reaction	Boundary		
1-0	Partially decomposed										
0-5	10YR5/2		LS	1f gr		V fr			CS		
5-20	7.5YR5/4		LS	1f gr		V fr			CS	C	
20-29	5YR5/6		SCL	2m SBK		fr				f1	
29-58	5YR4/6	f1 pockets uncoated sand	SL	1m SBK		V fr				Clay	
58-78	5YR4/6		SCL	1m SBK		V fr				Cla	

APPENDIX C

Measuring Bulk Density of Flow Restricting Layer

The clod method as described by Blake (2) was used to measure bulk density of six samples of kaolinitic clay collected in the field. The results are shown below.

Sample No.	Bulk density (Gm/cc)
1	1.78
2	1.76
3	1.71
4	1.68
5	1.77
6	1.82

Avg. 1.75 gm/cc

$\bar{S}x$ ± 0.02 gm/cc

APPENDIX D

Summary of precipitation, subsurface flow, surface runoff, and flow above B-horizon for individual storms

Storm date	Precipitation	Maximum 10-minute intensity	Subsurface flow		Surface runoff		Interflow (above B-horizon) 1/	
			Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
	Area inches	Inches/hour	Area inches		Area inches		Area inches	
1/21-22/71	1.93	3.00	0.03035	0.01043				
1/23-24/71	2.00	.45	.00476	.02510				
2/4/71	.95	3.50	.00716	.01169				
2/19-21/71	4.00	2.70	1.66642	2.21364				
3/6/71	.38	2.30	.00262	.00785	0.00422	0.00471		
4/20/71	1.85	2.10	.01094	.00093				
5/10/71	.56	3.00	.00740	.00192				
5/24/71	.58	1.50	.00568	.00176				
6/18/71	.63	3.42	.00294	.00264	0	T		
6/27/71	1.12	4.20	.05027	.02357	.00343	.00732		
7/23/71	1.35	4.50	.02645	.01382	.00475	.00218		
7/24/71	.65	2.40	.00350	.00335				
7/30/71	1.25	2.25	.00487	.00692				
8/31/71	1.18	2.55	.01072	.00640	0	.00063		
9/16/71	.55	1.20	.00517	.00040				
9/16/71	.60	1.50	.00857	.00428				
9/26/71	5.60	5.40	.23964	.22358	.02054	.02191		
12/9/71	.92	1.15	.04095	.00676				
12/12/71	.88	.90	.03960	.00839	T	0		
12/15/71	.44	2.20	.02138	.00640	T	0	T	0
12/30-31/71	.67	2.10	.01400	.00921				
1/1/72	3.50	1.20	.47907	.52908	.00138	0	T	0
1/3-4/72	1.56	.40	.75378	.81089				
5/7-8/72	3.05	2.10	.06606	.18519			T	0

1/ Apparatus for measuring interflow above B-horizon was installed November 1, 1971.

APPENDIX E

In-Situ Measurement of Hydraulic Conductivity Procedure

A modification of the shallow-well pump-in method as described by Boersma (3) was used to measure hydraulic conductivity in the field after disproportionate quantities of flow were observed through structural cracks in laboratory samples.

One hole was augered near each plot to a depth of 3 feet into the heavy clay layer. Aluminum tubing (1-5/8-inch inside diameter) was driven to within 6 inches of the bottoms of the auger holes. The holes were cleaned of loose soil and their exact depths were measured. The tubes were filled with water to within 6 inches of the tops. A water level sensor connected to a water stage recorder was installed in each tube so that the water level recessions could be monitored continuously. A period of five days was required before the clay (in the effective areas of the cavities) became saturated and the water levels began to drop at steady rates. The water levels were monitored for approximately one week after a steady-state condition was obtained. The tubes were refilled with water when necessary.

Having the water level recessions continuously traced on charts meant that hydraulic conductivity could be computed for several different time intervals and at various levels of hydraulic head. The following formula was used in computing conductivity:

$$K = \frac{\left[\ln \left(\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 - 1}\right) - 1\right] Q}{2 \pi h^2} \text{ inches per hour}$$

where K is hydraulic conductivity (inches per hour), h is average depth of water (inches) for a given time period (measured from the bottom of the hole), r is the radius of the hole (inches) and Q is the rate at which water is flowing into the soil (cubic inches per hour). The results are tabulated below:

Plot 1			Plot 2		
h (in.)	time (hr.)	K (in./hr.)	h (in.)	time (hr.)	K (in./hr.)
6.0	6	0.00018	5.5	5	0.00010
9.6	4	.00012	8.5	4	.00015
12.0	3	.00012	11.2	4	.00011
14.4	9	.00011	25.6	4	.00010
38.2	3	.00014	38.0	3	.00012
Average		0.00013			0.00011

The difference in mean conductivity for the two wells was not significant, so the average of both wells (0.00012 in./hr.) was used in computing water flux through the clay material.